Characterization of High-Burnup PWR and BWR Rods

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In support of a range of research programs relating to light water reactor fuel performance, high-burnup PWR and BWR rods and dry-cask-stored PWR rods were acquired recently under the sponsorship of the U.S. Nuclear Regulatory Commission, the U.S. Department of Energy, and the Electric Power Research Institute. Since the as-irradiated condition of these fuels is the prerequisite for test planning and evaluation, in-depth characterization of these fuels was undertaken. Equally important, these data could provide valuable input for burnup extension and dry-cask licensing renewal.

The fuels examined include PWR 15x15 fuel at 67 GWd/MTU burnup (73 GWd/MTU peak pellet) from the H. B. Robinson plant, BWR 9x9 fuel at 56 GWd/MTU burnup (64 GWd/MTU peak pellet) from the Limerick plant, and PWR 15x15 fuel at 36 GWd/MTU (40 GWd/MTU peak pellet) from the Surry-2 plant after 15-yr storage in a Castor-V/21 dry cask. The cladding for the H. B. Robinson and Surry fuel is Zircaloy4 and that for Limerick fuel is Zr-lined Zircaloy-2. In the characterization, significant effort is given to assess the condition of the cladding.

The overall condition of the H. B. Robinson rods examined appears to be sound, in spite of the high burnup. Fission gas release fraction was <~5% based on poolside Kr85 scans. The thicknesses of cladding OD oxide measured with optical metallography are 70 and 98 µm at axial elevations of 0 and 0.7 m above fuel midplane, respectively, for Rod A02. These values corroborated well the poolside eddy-current measurement results. Although the oxide contains numerous circumferentially oriented microvoids, spallation appears to be minimal. Hydrides in the cladding form a dense band adjacent to the OD oxide. Away from the OD, the density of hydrides diminishes with distance. The hydride platelets are mostly circumferentially oriented. Hydrogen contents of 580 and 750 wppm were measured at the 0 and 0.7 m axial elevations, corresponding to uptake percentages of 21 and 23%, respectively. Fuel/cladding gap is closed with little ID corrosion of the cladding. Thickness of rim fuel is ~600 µm, based on optical data.

Fission gas release in the Limerick rods ranges from 5 to 17%. The relatively high release may be related to the numerous microtears found in the fuel; such tears promote permeability with the rod plenum. Fission product deposits can be found in the now closed fuel/cladding gap. More substantial deposits are often located at the end of major radial fuel cracks, suggesting a vapor transport mechanism of the fission products down the temperature gradient. In spite of the deposits, reaction between the fission products and the cladding's Zr liner is modest. The OD oxide in the Limerick rods is thin, ranging from 5 to 25 µm circumferentially with an average of ~10 µm. Tenacious crud was found at some locations but the thickness is only ~5-10 µm and it varies inversely with the oxide layer thickness. Owing to the small oxide thickness, the density of hydrides in the Limerick cladding is low, with some platelets precipitated in the Zr liner. As in the case with the H. B. Robinson PWR fuel, the general condition of the Limerick BWR fuel also appears to be sound.

The Surry fuel rods were examined after 15-yr storage in a dry cask. Elevated cladding temperature, up to ~ 415C for several days, resulted from the cask thermal benchmark tests prior to the long-term storage. In the post-storage characterization of the rods, little evidence of deleterious effects, such as additional fission gas release or cladding creep, could be discerned. While the hydrogen contents in the cladding at near the midplane were as expected based on the oxide thickness data, that at a higher elevation appears to be low. Because the axial temperature distribution in the cask had a chopped cosine profile with the steep gradient away from the axial center, a plausible explanation could be the diffusion of hydrogen in the cladding towards the colder ends. Additional mapping of the hydrogen-content profile is needed to determine if axial migration is significant.